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Performance Evaluation of the Dual Digestion System

Montgomery (James M.), Inc., Pasadena, CA

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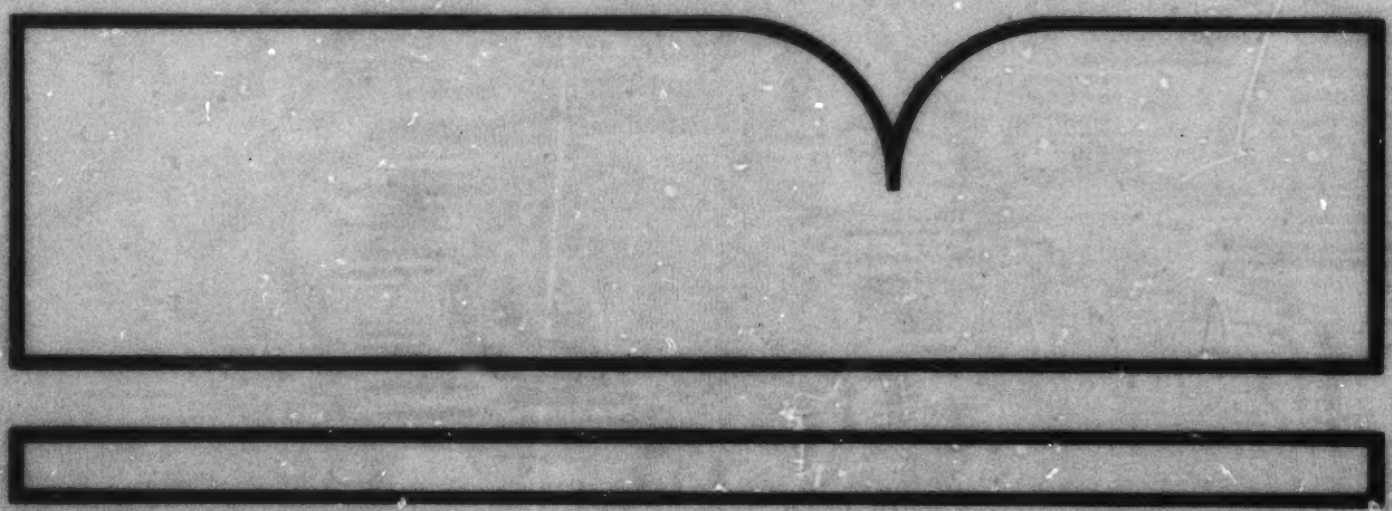

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by

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16. ABSTRACT

The dual digestion system (DDS) was developed to provide stabilized, pathogen-free sludge. DDS consists of a 1-day detention time, pure-oxygen, covered, aerobic digester (Step I) followed by an 8-day detention time anaerobic reactor. The temperature in the Step I digester is controlled by adjusting the pure oxygen feedrate. The heat generated through oxidation of volatile matter in the raw sludge is conserved in the Step I digester. No additional sludge heating is provided for anaerobic digestion in Step II so the biogas generated in Step II is available for other uses throughout the plant.

Operation of DDS during the special study at the Lackawanna Wastewater Treatment Plant demonstrated that adequate total volatile solids reduction could be achieved relative to processes to significantly reduce pathogens (PSRP) and processes to further reduce pathogens (PFRP). Reductions of the three indicator microbiological parameters of interest through DDS treatment were greater than those achieved by PSRPs and greater than or equal to those achieved by thermophilic aerobic digestion, a PFRP. Salmonella spp. data were difficult to compare, but it appears that greater reductions of this pathogenic bacteria can be achieved with PSRPs. Regrowth of Salmonella spp. in the Step II digester was not observed during this study.

17. KEY WORDS AND DOCUMENT ANALYSIS

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PERFORMANCE EVALUATION OF THE DUAL DIGESTION SYSTEM

by

A. RON APPLETON, JR. and CAROLE J. LEONG

The development of municipal wastewater sludge treatment processes which produce a stabilized sludge, in which pathogens are reduced to an acceptable level, is important to provide the greatest number of options for ultimate sludge disposal. In defining an acceptable degree of sludge treatment, the USEPA developed two classifications of processes, Processes to Significantly Reduce Pathogens (PSRP) and Processes to Further Reduce Pathogens (PFRP).[1] Treatment by a PSRP will produce a sludge acceptable for land application provided that public access is controlled for at least 12 months, grazing by animals whose products are consumed by humans is prevented for at least one month, and food crops for direct human consumption (in which the sludge contracts the edible part of the plant) are not grown within 18 months. Sludge applied to land used for growing crops within 18 months (in which the edible part of the plant is contacted) needs to be treated by a PFRP. The other two restrictions on access and grazing also apply to PFRP treated sludge. PSRPs and PFRPs are defined in terms of a number of processes operated under specified conditions (e.g., anaerobic digestion for 15 days at 35° C to 50° C with a volatile solids reduction of at least 38% is a PSRP). Other treatment methods and/or operating conditions may be acceptable to be included in either classification provided the volatile solids reduction and pathogen destruction are equivalent to those provided by the specific processes named.

The Dual Digestion System (DDS) was developed to provide stabilized, pathogen-free sludge. DDS consists of a one day detention time, pure oxygen, covered, aerobic digester (Step I) followed by an eight day detention time anaerobic reactor. The temperature in the Step I digester is controlled by adjusting the pure oxygen feedrate. The heat generated through oxidation of volatile matter in the raw sludge is conserved in the Step I digester. No additional sludge heating is provided for anaerobic digestion in Step II, so the biogas generated in Step II is available for other uses throughout the plant.

DDS was developed by Union Carbide Corporation in the 1970s and is currently marketed by the Lotepro Corporation (New York, NY). Details of the development are presented in Drnevich and Matsch[2] and Castillo, et al.[3] Bench- and pilot-scale testing of DDS indicated solids destruction comparable to conventional biological processes. Based on the results presented by Drnevich and

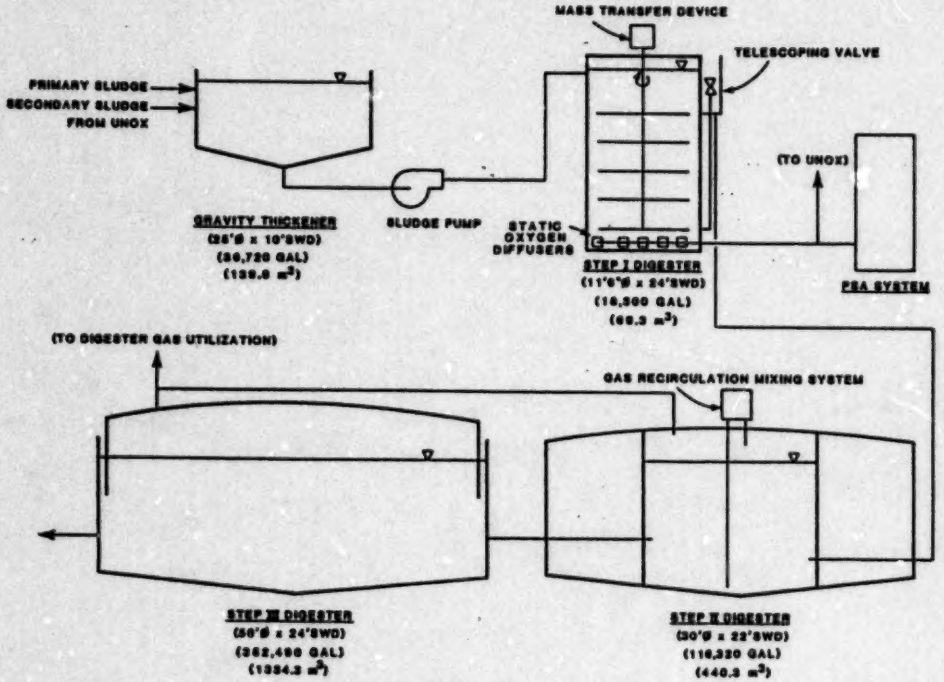
Matsch,[2] the reduction of Salmonella spp. and Pseudomonas aeruginosa to below their detection limit of 3 organisms/100 ml wet sludge could be accomplished within several hours at 55° C. The one day design detention time provided in the Step I digester was judged adequate to achieve "pasteurization" of the sludge.

The bench- and pilot-scale work with DDS also indicated cost savings for producing a stabilized, pasteurized sludge compared to conventional processes. DDS was demonstrated in full-scale operation at the Hagerstown WWTP in late 1980 and early 1981.[4] This study showed that thermophilic temperatures could be achieved in the full-scale aerobic digester with detention times ranging between 0.99 and 2.25 days. During the 20 weeks of operation, the solids concentration and sludge flowrate varied considerably, but thermophilic temperatures were able to be maintained. A temperature of 50° C was achieved about one week after start-up of the system. During the study, average volatile solids removal was 27.2% in Step I and 41.6% overall.

Significant reductions of pathogens and pathogen indicators were observed. Details of this aspect of the demonstration study are discussed in a subsequent section.

To date, DDS has been installed at three treatment plants in the U.S.: Nutbush Creek WWTP (Henderson, NC), Lackawanna WWTP (Lackawanna, NY), and a second Step I digester has been added to the Hagerstown WWTP. The DDS system at all three plants received an increased level of funding through the Innovative/Alternative (I/A) technology program. All three plants include the UNOX process in their secondary treatment scheme, so the costs for pure oxygen for DDS were expansion increments to the base cost of a pressure swing adsorption (PSA) oxygen generation system sized to meet UNOX demands. This resulted in a higher calculated cost savings of DDS than if DDS had been the only process requiring pure oxygen. All three plants are also similar in that they formerly used conventional two-stage anaerobic digestion. A new reactor was constructed to serve as the Step I digester to accomplish the change from two-stage digestion to DDS, and the former first-stage digester was modified to serve as the Step II digester. The former second stage digester at each location provides some additional solids stabilization and some solid/solution separation through gravity thickening. This last stage of treatment is not strictly a component of DDS, but is called the Step III digester.

Figure 1 is a schematic of the DDS system at the Lackawanna WWTP. Sludge is continuously fed to the Step I digester from the gravity thickener. The level of sludge in the Step I digester can be controlled to some degree by a telescoping valve. High levels of oxygen transfer are achieved in Step I by the mass transfer device which slowly rotates, shearing the rising oxygen bubbles to provide a higher interfacial surface area. A lithium chloride tracer test conducted during this study showed that the Step I digester is well mixed. To provide a Step II



DDS SCHEMATIC AT LACKAWANNA WWTP

FIGURE 1

design detention time of approximately 8 days, a smaller diameter reactor was constructed within the old digester. The gas recirculation mixing system in Step II failed five weeks into the study, so mixing was provided by pumped recirculation. Biogas produced through anaerobic digestion in the Step II and Step III digesters can be used to fuel a gas engine to drive the PSA compressor or to provide space heating requirements.

Under contract to the USEPA, James M. Montgomery, Consulting Engineers, Inc. (Pasadena, CA) is currently evaluating the demonstrated, full-scale performance of a number of I/A technologies. All three facilities listed above were visited as part of a post-construction evaluation (PCE) of the DDS process. In addition, a special study was carried out at the Lackawanna WWTP to investigate the performance of DDS in achieving pathogen destruction and solids stabilization. The results of this study are presented below. The complete evaluation is described in detail in the project final report.[5]

ANALYTICAL METHODS

Microbiological sampling at the Lackawanna WWTP was conducted in three separate phases of approximately ten weeks each. The sampling program was designed to obtain thirty samples for adequate characterization of the degree of microbial destruction provided by DDS. The first sampling period was between July 2, 1984 and September 10, 1984. During this phase, microbiological samples were analyzed for total coliform and fecal coliform by Ecology and Environment, Inc. (Buffalo, NY). For three of the ten weeks (August 8 - 22) during the first sampling period, sludge was hauled from a nearby treatment plant to maintain adequate solids loading while operating closer to the Step I design hydraulic detention time of 1.17 days. These three weeks are subsequently referred to as Phase IB and the remaining seven weeks as Phase IA. The second sampling period, Phase II, was from September 19 to December 7, 1984. The third sampling period, Phase III, was from February 13 to April 24, 1985. During the last two phases, samples were analyzed for total coliform, fecal coliform, fecal streptococci, and Salmonella spp. by Montgomery Laboratories (Pasadena, CA). In all three phases, samples were analyzed for total solids in order to calculate microbial densities for quantified samples in the units of most probable number (MPN) per gram of dry sludge.

Treatment plant operators collected the grab samples during all three phases. Samples were collected downstream of the sludge pump, from the telescoping valve at the Step I digester, and from the Step II digester in sterile plastic containers. During Phases IA and IB, samples were stored in the plant laboratory refrigerator at 4° C prior to same-day delivery to the analytical lab. During Phases II and III, samples were cooled to 4° C, packed in ice, and shipped via an overnight courier to Montgomery Laboratories. Within several hours after arrival, the sludge samples were analyzed for parameters of interest.

The analytical procedures used for analysis of the indicator organisms total coliform, fecal coliform, and fecal streptococci and of the pathogenic bacteria of the Salmonella spp. are described below. In addition, the results of an attempt to develop a procedure for the analysis of enterococci are discussed.

Coliform Bacteria. Five tube, five dilution tests were conducted according to Standard Methods.[6] Lauryl tryptose broth (Difco) was used as presumptive media. Positive tubes showing growth and gas production were transferred to BGB and EC media (Difco) for the confirmed test. The MPN index for total and fecal coliforms was calculated from the positive confirmed tubes in BGB and EC respectively. For each sampling date, one positive confirmed tube was run through the completed test to verify the test results.

Fecal Streptococci. Five tube, five dilution MPN tests were conducted according to Standard Methods.[6] Azide dextrose broth (Difco) was used as the presumptive media. Positive tubes showing turbidity after 24 and 48 hours growth were streaked onto bile esculin azide agar plates (Difco) for confirmation. Plates having typical colonies with a brown halo were scored as positive, and the MPN index was calculated from the confirmed positive plates.

Salmonella spp. A modified Kenner-Clark procedure[7] was used to enumerate the Salmonella spp. A five tube, three dilution MPN test was performed using a selenite ducitol enrichment medium as the presumptive medium. 10, 1, and 0.1 ml aliquots of sludge were innoculated directly into the presumptive media and incubated at 40° C. Because the sludge made it difficult to score the tubes, all tubes were streaked onto XLD agar plates (Difco) after 48 hours of incubation for primary isolation of Salmonella. Streaking at 48 hours seemed to eliminate some of the problems encountered with the overgrowth of Proteus spp. when the presumptive tubes were transferred at 24 hours. Positive plates having clear colonies with black centers were restreaked onto XLD plates to obtain isolated colonies subsequently used for biochemical testing.

Salmonella colonies were picked from the XLD agar plates and tested on triple sugar iron agar (TSI, Difco), lysine iron agar (LIA, Difco) and Christensen's urea agar. Only those isolates showing the typical reactions of Salmonella on the test media were further confirmed by serological testing. Positive cultures were tested against Salmonella O Antiserum Poly A-1 (Difco). The MPN index was calculated based on the results of the serological tests.

Enterococci. A five tube MPN test was used to estimate the concentration of enterococci. This method used a highly selective media for the presumptive phase, and bile esculin azide agar (BEA) for the confirmation phase. Decimal dilutions of the sludge were innoculated into modified enterococci media[8] and

incubated at 42 ° C for 48 hours. After 24 and 48 hour incubation, presumptive positive results were indicated by turbidity. Sterile, wooden applicator sticks were used to transfer innoculum from the positive tubes to the confirmation media, BEA, and incubated for 24 hours at 35° C. The presence of brownish-black colonies with brown halos confirms presence of fecal streptococci, and was used to calculate the MPN index.

As a quality assurance procedure, brain heart infusion (BHI) broth tubes were innoculated with typical colonies from BEA plates from each sample and incubated for 24 hours at 45° C. Growth after 24 hours and a negative catalase test provided further verification of the presence of fecal streptococci.

Isolates from several BEA plates were also identified using the API 20S Streptococcus Test System. Two species of fecal streptococci were identified from the isolates tested. These were S. faecalis and S. faecium, members of the enterococci group of the fecal streptococci, indicating that the test was selective for members of the enterococci group.

A comparison of the concentrations of fecal streptococci to the concentrations of enterococci showed that the fecal streptococci concentrations were approximately two orders of magnitude greater. This difference prompted an identification of isolates obtained in the fecal streptococci test. Isolates from nine different samples were selected from positive portions in dilutions which did not have corresponding positive results in the enterococci test. All the isolates tested were identified as either S. faecalis or S. faecium, members of the enterococci group which should have been isolated in the enterococci test.

It appears that based on the higher recoveries of enterococci using the azide dextrose broth in the fecal streptococci procedure, this method did not recover all of the enterococci present in the sample. Almost all the presumptive tubes in the enterococci test were confirmed on BEA, suggesting that the presumptive media or incubation conditions may be too inhibitory for this population of enterococci.

Performance of DDS with respect to conventional operating parameters was monitored by analyzing data routinely collected by the operators (e.g., sludge influent pumping flowrate, Step I pure oxygen feedrate and purity). Sludge grab samples were also collected by the operators three times a day at the sites used for microbiological sampling and used to make a daily composite. Sludge temperatures were measured in the morning grab sample. This composite was analyzed in the plant laboratory for pH, alkalinity, total solids, and total volatile solids following Standard Methods.6

RESULTS AND DISCUSSION

The results of the microbiological analyses and the total solids analyses were used to calculate microbial densities in units of

most probable number (MPN) per gram of dry sludge. Although 30 samples were taken during each sampling period, microbial densities could only be calculated for those samples which could be quantified. Because the concentration in some samples was below the detection limit or too numerous to count, less than 30 values were able to be statistically analyzed.

Figures 2 through 11 present the microbiological results. The total coliform results for Phases I through III are plotted in Figures 2 through 4. The upper half of each figure contains a time series plot showing total coliform density versus date at each sampling site. The lower half of each figure contains a cumulative probability distribution plot of the data from each sampling site. A best-fit straight line was plotted through the actual data points graphed on a logarithmic scale. As shown in the figures, this straight line distribution fits the data very well and indicates that the microbiological densities at each sampling site are log-normally distributed. These cumulative probability plots are useful to visually illustrate the geometric mean of the data, represented by the 50-percentile concentration, and the variability, represented by the slope. For example, the data in Figure 2 indicate that the total coliform density in the Step I effluent is more variable than in the Step I influent because of the relatively steeper slope of the log-normal distribution.

The fecal coliform results are plotted in Figures 5 through 7 for the three sampling phases. Results for fecal streptococci and Salmonella spp. are plotted in Figures 8 and 9, and 10 and 11, respectively.

Table I summarizes the microbiological sampling results for the entire project. The number of samples quantified, the geometric mean, and the spread factor are listed. The raw sludge mean concentrations of the microbiological parameters increase in the order Salmonella spp., fecal streptococci, fecal coliform, and total coliform. The "spread factor" is a measure of the dispersion of a log-normally distributed random variable. It is analagous to the standard deviation in normally distributed data but applies as a multiplicative factor. For example, 68.3% of the distribution of a parameter would fall between M/S and M*S, where M is the geometric mean and S is the spread factor.

To help interpret observed microbiological destruction average values of conventional process parameters for each of the phases are presented in Table II. Because the Lackawanna WWTP was operating at less than its design capacity, the solids production within the plant was not great enough to allow DDS operation near the Step I design detention time of 1.17 days. Sludge was hauled from a nearby municipal wastewater treatment plant during Phase IB to augment normal solids production. During this three week period, DDS was operated at the design detention time and close to the design total volatile solids loading of 2530 kg/d. However, the total solids loading was

TABLE I

MICROBIOLOGICAL SAMPLING RESULTS

Parameter	PHASE IA n	PHASE IA Geometric Mean[a]	PHASE IA Spread Factor	PHASE IB n	PHASE IB Geometric Mean[a]	PHASE IB Spread Factor	PHASE II n	PHASE II Geometric Mean[a]	PHASE II Spread Factor	PHASE III n	PHASE III Geometric Mean[a]	PHASE III Spread Factor
Total Coliform												
Step I Influent	17	1.22×10^6	3.57	7	1.46×10^6	2.56	26	1.31×10^8	3.53	29	7.17×10^7	3.14
Step I Effluent	17	7.42×10^2	9.44	4	2.26×10^3	21.01	26	7.28×10^3	20.26	22	4.92×10^4	38.4
Step II Effluent	14	1.53×10^2	8.00	5	1.62×10^3	8.52	28	3.70×10^2	14.30	25	3.71×10^4	15.3
Fecal Coliform												
Step I Influent	18	2.86×10^5	5.83	7	2.30×10^5	2.80	26	2.25×10^7	3.19	29	1.54×10^7	3.05
Step I Effluent	16	5.01×10^2	10.83	5	6.01×10^3	5.38	26	3.78×10^3	23.14	23	3.28×10^4	43.22
Step II Effluent	11	1.04×10^2	9.37	4	1.13×10^3	10.69	27	1.96×10^2	11.00	25	2.11×10^4	13.27
Fecal Streptococci												
Step I Influent		NA			NA		29	6.69×10^6	2.65	30	4.46×10^6	3.79
Step I Effluent		NA			NA		30	4.90×10^4	6.57	24	2.43×10^5	6.65
Step II Effluent		NA			NA		30	6.56×10^3	5.19	25	5.79×10^4	8.48
Salmonella spp.												
Step I Influent		NA			NA		29	1.33×10^1	3.95	25	4.95	5.52
Step I Effluent		NA			NA		7	1.68	1.68	26	8.03	17.56
Step II Effluent		NA			NA		6	1.14	1.14	28	9.74	10.14

NA: not analyzed

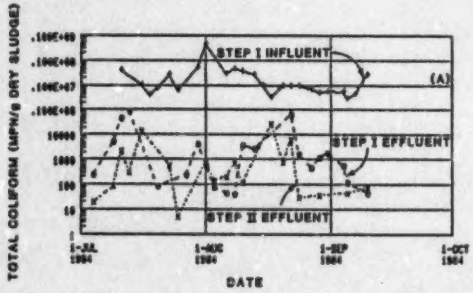
[a]: concentration in MPN/g dry sludge

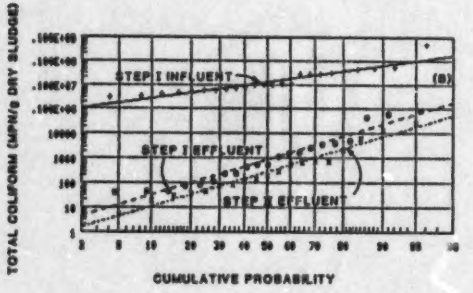
TABLE II

DUAL DIGESTION SYSTEM PERFORMANCE SUMMARY

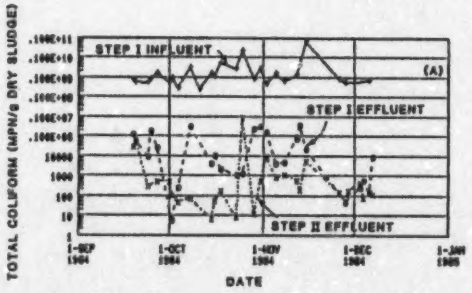
Parameter	Units	Phase IA[a]	Phase IB[a]	Phase II[a]	Phase III[a]
Step I Residence Time	d	1.76	1.13	1.80	2.00
Temperature:					
Ambient Air	°C	18.4	20.4	6.0	1.3
Step I Influent	°C	21.4	22.5	17.6	12.2
Step I Effluent	°C	52.5	49.9	51.6	46.6
Step II Effluent	°C	43.6	45.1	44.1	36.8
pH:					
Step I Influent	pH units	6.12	6.12	6.37	6.30
Step I Effluent	pH units	7.30	7.11	7.35	7.35
Step II Effluent	pH units	7.49	7.36	7.43	7.20
Alkalinity:					
Step I Influent	mg/l as $CaCO_3$	1,533	2,016	1,596	2,165
Step I Effluent	mg/l as $CaCO_3$	2,811	2,932	2,865	5,128
Step II Effluent	mg/l as $CaCO_3$	5,032	4,314	4,038	5,936
Total Inert Solids Removal:					
Step I	%	6.6	0.9	2.2	6.7
Step II	%	-14.6	16.2	-2.3	-9.8
Overall	%	-7.1	17.0	0.0	-2.4
Total Volatile Solids Removal:					
Step I	%	17.7	13.7	21.2	14.7
Step II	%	23.5	24.8	29.5	14.3
Overall	%	37.1	35.1	44.4	26.9
Total Volatile Solids Loading - Step I	kg/d	1,042	1,500	1,000	1,184
Total Volatile Solids: Total Solids Ratio	(-)	0.63	0.55	0.69	0.61
Step I Oxygen Feedrate	kg/d	582	591	636	668

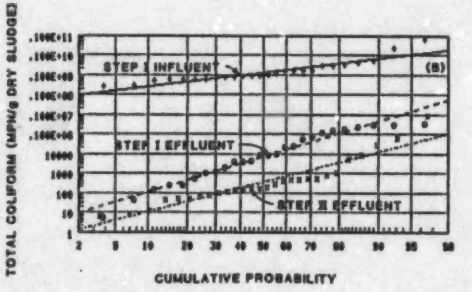
[a]: values reported are geometric means



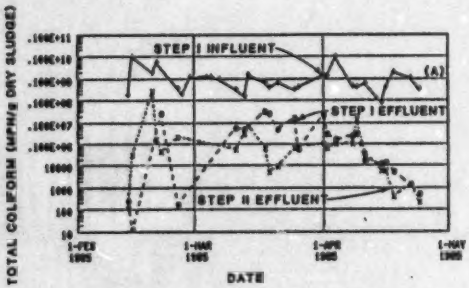


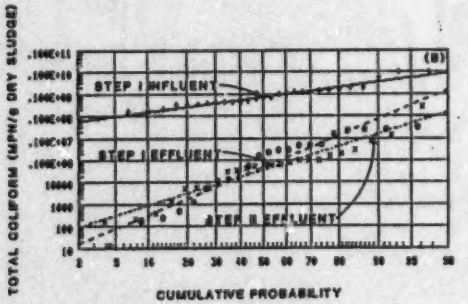
TOTAL COLIFORM CONCENTRATION
PHASES IA & IB
FIGURE 2



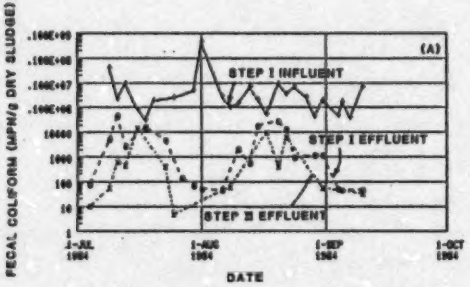


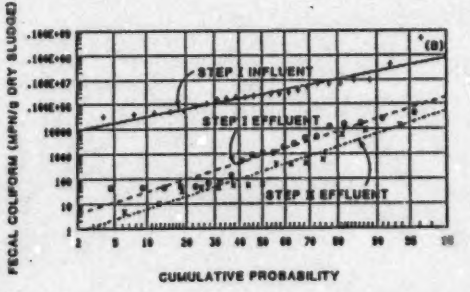
TOTAL COLIFORM CONCENTRATION
PHASE II
FIGURE 3



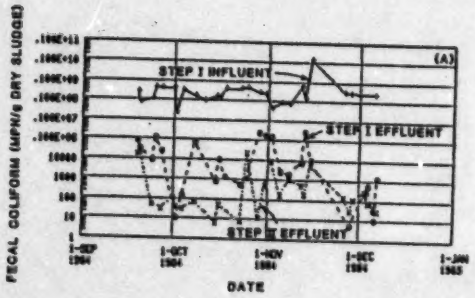


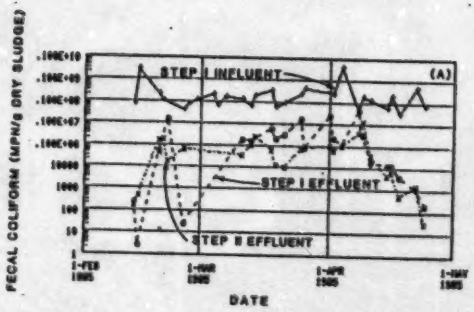
TOTAL COLIFORM CONCENTRATION
PHASE II
FIGURE 4

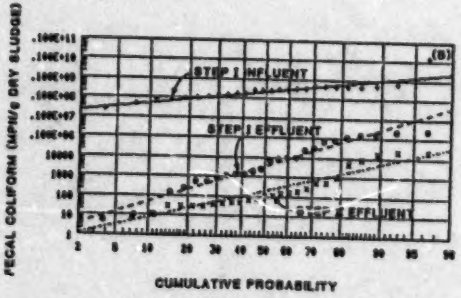




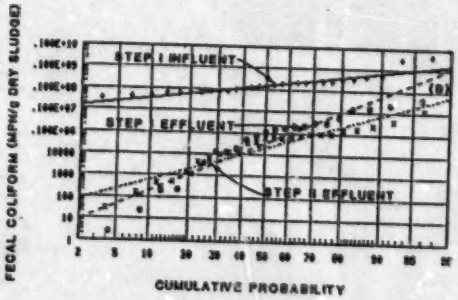
FECAL COLIFORM CONCENTRATION
PHASE IA & IB
FIGURE 5



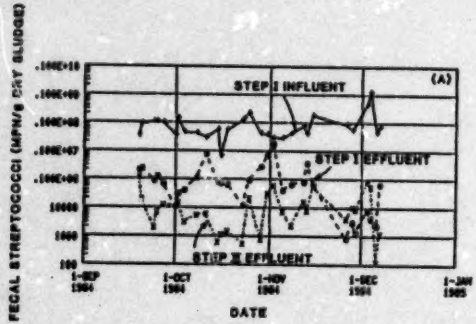




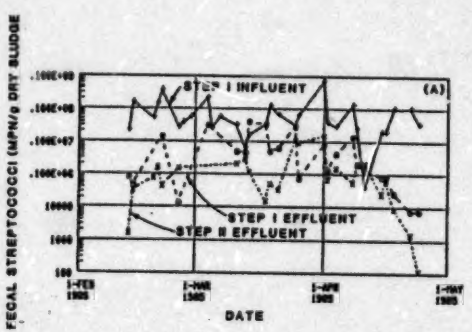
FECAL COLIFORM CONCENTRATION
PHASE II
FIGURE 6



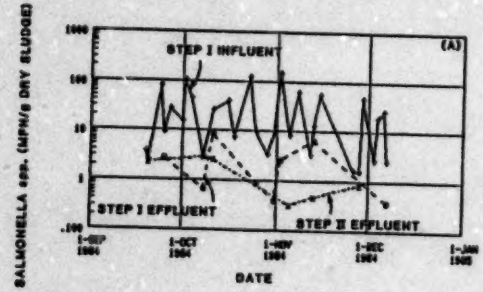
FECAL COLIFORM CONCENTRATION
PHASE III
FIGURE 7

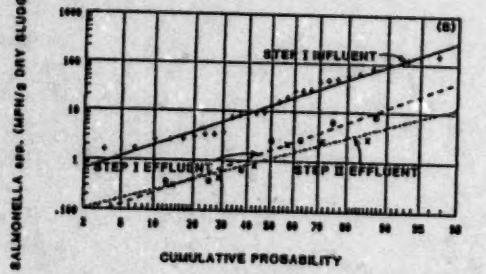


FECAL STREPTOCOCCI CONCENTRATION
PHASE II
FIGURE 8

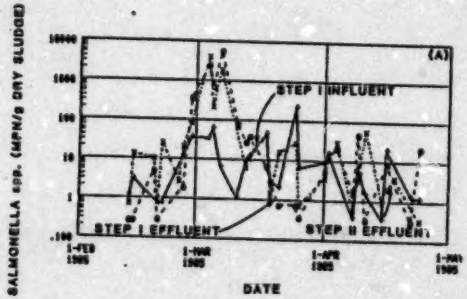


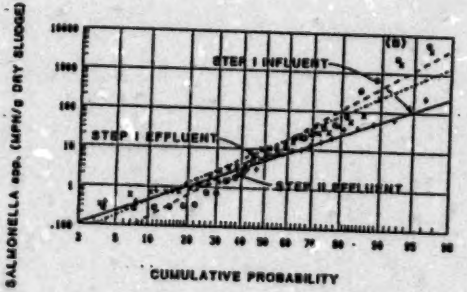
FECAL STREPTOCOCCI CONCENTRATION
PHASE III
FIGURE 9





SALMONELLA spp. CONCENTRATION
PHASE II
FIGURE 10





SALMONELLA spp. CONCENTRATION
PHASE III
FIGURE 11

high due to the low total volatile solids:total solids ratio of the additional sludge.

The desired Step I temperature during all three phases of this study was 55° C. Although the Step I temperatures often reached or exceeded this goal during all phases, the mean temperatures were all less than 55° C. The highest single daily temperature was 63° C during Phase IB. During Phase III, a major process upset occurred for several weeks in the middle of the sampling period (February 26 - April 5) and the Step I temperature reached a low of 34° C. Operating data collected by the operators indicated that the oxygen feedrate was highest during this period, an anomalous result. Plant personnel were not able to determine the cause of the process upset. The effects of the temperature drop are reflected in the microbiological densities in the time series plots. Reductions again reached high levels as the Step I temperature reached 55° C at the end of Phase III.

The increase of raw sludge pH and alkalinity through aerobic treatment in Step I results in more stable operation in the anaerobic portion of DDS.

An analysis of the average removal of total inert solids, which should be a conservative parameter, across the Step I and Step II digesters shows that the solids are balanced across the s[illegible]. The poorest balance was observed during Phase IB. The mea[illegible] total volatile solids concentration during each period was used to calculate the total volatile solids reductions listed in Table I. Step I of DDS is claimed to remove between 10-15% of the volatile solids when Step I is operated in the thermophilic mode.[9] Higher removals in Step I have been observed by others in a previous study at the Lackawanna WWTP (e.g., 22%)[9] and in all phases of this study, except Phase IB. Overall volatile solids destruction ranged from a high of 44% in Phase II to a low of 27% in Phase III. An earlier study at the Lackawanna WWTP by Ryan and Pieczonka[9] under similar operating conditions reported a higher overall volatile solids reduction of 62%. The minimum volatile solids reduction listed for processes classified as either PSRP or PFRP is 38%.[9] This is felt to be the minimum volatile solids reduction necessary to prevent attraction of disease vectors (e.g., flies, rodents).

One reason for the low volatile solids reduction could result from the temperatures observed in the Step II digester. As discussed in the Process Design Manual: Sludge Treatment and Disposal,[10] the optimal temperatures for growth of anaerobic organisms which stabilize the volatile solids through conversion to methane gas are approximately 35° C and 54° C. Between these two temperatures, gas production decreases and reaches a minimum at approximately 43°C. The mean temperature in the Step II (i.e., anaerobic) digester was close to this non-optimal temperature.

To overcome this problem when operating the Step I digester in the thermophilic mode, the system at Hagerstown WWTP uses the heat exchangers from the former two-stage anaerobic digestion system to cool the sludge. Plant service water is circulated through the heat exchanger to cool the sludge to approximately 35° C.

The extent of microbial destruction provided by DDS was calculated based on the number of quantified samples, geometric mean, and spread factor in the equations used by McCarty, et al.[11] A statistical analysis of the data, as summarized in Table I, provided sufficient information to calculate the mean log reduction for each parameter across each digester as well as the 95% confidence interval of the removal, which accounts for the variability of the data. These results for reduction across each digester, and across the entire DDS process, are presented for each microbiological parameter in Tables III through VI. The best performance of DDS with respect to microbial destruction was observed during Phase II. As expected, the majority of microbial inactivation was provided by the Step I digester. Reductions in microbial parameters observed during this study in Phases IA, IB and III were comparable to those observed by Haas[4] during the full-scale demonstration of DDS. Reductions observed during Phase II were approximately 1 1/2 orders of magnitude greater than those observed by Haas.[4]

Similar to results reported by Berg and Berman[12] and Pederson,[13] the reductions of the microbiological parameters decreased in the order total coliform, fecal coliform, fecal streptococci, and Salmonella spp. For example, the ratio of an easily quantified indicator organism, such as total coliform, to pathogenic bacteria of the Salmonella spp. decreases through DDS treatment. Fecal streptococci provides the most conservative parameter for indicating the reduction of pathogens, as measured by Salmonella spp.

An increase in the concentration of Salmonella spp., indicative of regrowth, was observed, in the full-scale demonstration of DDS at Hagerstown WWTP reported by Haas.[4] During the two phases of this study in which samples were analyzed for Salmonella spp., regrowth was not observed during Phase II. However, because of the abnormal low operating temperatures observed during Phase III, initial reductions of Salmonella spp. were not achieved in Step I. Salmonella spp. densities continuously increased across DDS in Phase III, approximately doubling in concentration.

The effectiveness of DDS in achieving pathogen destruction in comparison to processes classified as PSRP or PFRP was evaluated by comparison to previous study results. Data summarized in a literature review by Pederson[13] described observed reductions for PSRPs. The effectiveness of thermophilic aerobic digestion, a PFRP, was calculated using the geometric mean of the data reported by Jewell, et al.[14] A summary of the average log

reductions of the four parameters of interest achieved through these processes is presented in Table VII.

For all parameters except Salmonella spp., the log reductions observed in this study are greater than or equal to those for the PSRPs listed in Table VII. Comparing the performance of DDS during peak operation in Phase II to that of thermophilic aerobic digestion, a PFRP, greater reductions of total coliform and fecal coliform were observed for DDS. Fecal streptococci reductions were nearly equal for the two processes. It is difficult to accurately compare the reductions in Salmonella spp. because of their low raw sludge concentrations relative to their analytical detection limit of 2 MPN/100 ml. As shown in Table I, during Phase II, out of 29 samples in which Salmonella spp. could be quantified in the Step I influent, only 7 were quantified in the Step I effluent and only 6 were quantified in the Step II effluent. Because the reductions shown in Tables III through VI were calculated using quantified data, as MPN/g dry sludge, the log reduction of Salmonella spp. was greater than 1.1 during Phase II. This makes comparison with other Salmonella spp. data difficult.

SUMMARY

Operation of DDS during the special study at the Lackawanna WWTP demonstrated that adequate total volatile solids reduction could be achieved relative to PSRPs and PFRPs. Reductions of the three indicator microbiological parameters of interest through DDS treatment were greater than those achieved by PSRPs and greater than or equal to those achieved by thermophilic aerobic digestion, a PFRP. Salmonella spp. data were difficult to compare, but it appears that greater reductions of this pathogenic bacteria can be achieved with PSRPs. Regrowth of Salmonella spp. in the Step II digester was not observed during this study.

However, questions remain about the full-scale operational and mechanical reliability of DDS. Although Step I digester temperature often exceeded the thermophilic operating goal of 55° C during all three operating phases, the temperature varied sufficiently day to day such that the mean temperatures were less than desired. In addition, the Step I mass transfer device failed recently at the Lackawanna WWTP due to a bent central shaft. At a new treatment facility with DDS as the sole method of solids stabilization, such a mechanical failure would require a back-up treatment method.

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TABLE III

TOTAL COLIFORM REDUCTION

	Log Reduction		
	Mean	95% Confidence Interval	
		Lower	Upper
PHASE IA			
Influent - Step I	3.2	2.7	3.8
Step I - Step II	0.7	-0.1	1.4
Overall	3.9	3.3	4.5
PHASE IB			
Influent Step - Step I	2.8	1.3	4.3
Step I - Step II	0.1	-1.7	1.9
Overall	2.9	2.0	3.9
PHASE II			
Influent Step I	4.3	3.7	4.8
Step I - Step II	1.3	0.6	2.0
Overall	5.5	5.1	6.0
PHASE III			
Influent - Step I	3.2	2.5	3.9
Step I - Step II	0.1	-0.7	1.0
Overall	3.3	2.8	3.8

TABLE IV

FECAL COLIFORM REDUCTION

	Log Reduction		
	Mean	95% Confidence Interval	
		Lower	Upper
PHASE IA			
Influent - Step I	2.8	2.7	3.4
Step I - Step II	0.7	-0.1	1.5
Overall	3.4	2.7	4.1
PHASE IB			
Influent Step - Step I	1.6	0.8	2.4
Step I - Step II	0.7	-0.7	2.1
Overall	2.3	1.1	3.5
PHASE II			
Influent Step I	3.8	3.2	4.3
Step I - Step II	1.3	0.6	2.0
Overall	5.1	4.6	5.5
PHASE III			
Influent - Step I	2.7	2.0	3.4
Step I - Step II	0.2	-0.6	1.0
Overall	2.9	2.4	3.3

TABLE V

FECAL STREPTOCOCCI REDUCTION

	Log Reduction		
	Mean	95% Confidence Interval	
		Lower	Upper
PHASE II			
Influent Step I	2.1	1.8	2.5
Step I - Step II	0.9	0.5	1.3
Overall	3.0	2.7	3.3
PHASE III			
Influent - Step I	1.3	0.9	1.7
Step I - Step II	0.6	0.1	1.1
Overall	1.9	1.5	2.3

TABLE VI

SALMONELLA spp. REDUCTION

	Log Reduction		
	Mean	95% Confidence Interval	
		Lower	Upper
PHASE II			
Influent - Step I	0.9	0.4	1.4
Step I - Step II	0.2	-0.4	0.8
Overall	1.1	0.7	1.5
PHASE III			
Influent - Step I	-0.2	-0.8	0.4
Step I - Step II	-0.1	-0.7	0.5
Overall	-0.3	-0.8	0.2

TABLE VII
MICROBIOLOGICAL REDUCTIONS BY SLUDGE STABILIZATION PROCESSES

Process	Log Reduction			
	Total Coliform	Fecal Coliform	Fecal Streptococci	Salmonella spp.
High Rate Anaerobic Digestion	2.05	1.84	1.48	1.63
Mesophilic Aerobic Digestion	-[a]	-[a]	-[a]	-[a]
Mesophilic Composting	>3	>4	-[b]	1-3[c]
Lime Stabilization	-[a]	>2	-[b]	>2
Thermophilic Aerobic Digestion	4.1[d]	3.1[d]	3.3[d]	>1.9

From references 13 and 14.

[a]: Little data available.

[b]: Resistant to inactivation.

[c]: Final densities less than or equal to 10 MPN/g dry sludge.

[d]: Calculated using quantified data; i.e., conservative reductions.

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